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Design of Electronic Circuit Model of Neural System Based on Hybrid Dynamical System

Kentaro Takeda, Chiaki Matsuda, Hiroyuki Torikai†

†Department of Computer Science, Kyoto Sangyo University
Motoyama, Kamigamo, Kita-Ku, Kyoto 603-8555, Japan
Email:torikai@cse.kyoto-su.ac.jp

Concerning modeling methods of neural systems, there exist four approaches depending on continuousness of time and state as follows. The first approach is to model a neural system by using a nonlinear ordinary differential equation (ODE), which has a continuous time and continuous states (CTCS). Such a CTCS model can be implemented by a nonlinear electronic circuit. The second approach is to model a neural system by using a nonlinear difference equation, which has a discrete time and continuous states (DTCS). Such a DTCS model can be implemented by a switched capacitor circuit. The third approach is to model a neural system by using a numerical integration in a fixed-point or a floating-point number format or by a cellular automaton, which have discrete times and discrete states (DTDS). Such DTDS models can be implemented by a digital signal processor or a sequential logic. Most neural system modeling approaches are belonging to one of the above three ones. On the other hand, our group has been developing the *fourth missing approach*, i.e., to model a neural system by using an asynchronous cellular automaton, which has a continuous (state transition) time and discrete states (CTDS), e.g., [1]-[3]. Such a CTDS model can be implemented by an asynchronous sequential logic. It should be emphasized that the dynamics of the CTDS model can be reduced into a hybrid Poincare map [4] having discrete states (corresponding to discrete states of the CTDS system) and continuous states (corresponding to phases of asynchronous clocks).

In this paper, we introduce our recent results on CTDS neural system models. Typically, such a CTDS neural system model has some discrete states, e.g., $X \in \{0, 1, \cdots, L-1\}$, $Y \in \{0, 1, \cdots, M-1\}$, and $Z \in \{0, 1, \cdots, N-1\}$, where L, M, and N determine the resolution of the state space. Also, the model typically has multiple asynchronous clocks, e.g., $C_X(t)$, $C_Y(t)$, and $C_Z(t)$. These clocks trigger asynchronous state transitions as follows.

$$\begin{aligned}
&\text{If } C_X(t) = 1, \quad \text{then } X(t_+) = F_X(X(t), Y(t), Z(t)),\\
&\text{If } C_Y(t) = 1, \quad \text{then } Y(t_+) = F_Y(X(t), Y(t), Z(t)),\\
&\text{If } C_Z(t) = 1, \quad \text{then } Z(t_+) = F_Z(X(t), Y(t), Z(t)),
\end{aligned}$$

where $F_X \in \{-1, 0, 1\}$, $F_Y \in \{-1, 0, 1\}$, and $F_Z \in \{-1, 0, 1\}$ are discrete functions, which determine the nonlinear vector field of the model and are implemented by logic gates (corresponding to nonlinear functions) and reconfigurable wires (corresponding to control parameters). In the presentation, we will show our recent CTDS neural system models such as cochlea model [1], calcium-based spine model [2], gene network model [3], and central pattern generator model [5] (see also Fig. 1).

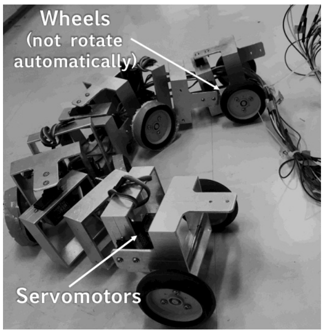

Figure 1: Snake robot controlled by a CTDS model of central pattern generator [5].

References

[1] K. Takeda and H. Torikai, A Novel Hardware-Efficient Cochlea Model based on Asynchronous Cellular Automaton Dynamics: Theoretical Analysis and FPGA Implementation, IEEE Trans. CAS-II (accepted).

[2] K. Isobe and H. Torikai, A novel hardware-efficient asynchronous cellular automaton model of spike-timing dependent synaptic plasticity, IEEE Trans. CAS-II, Vol. 63, No. 6, pp. 603 - 607, 2016.

[3] T. Yoshimoto and H. Torikai, A Novel Hardware-Efficient Gene Network Model based on Asynchronous Cellular Automaton Dynamics, NOLTA, IEICE (accepted).

[4] C. Matsuda and H. Torikai, A Novel Generalized PWC Neuron Model: Theoretical Analyses and Efficient Design of Bifurcation Mechanisms of Bursting, IEEE Trans. CAS-II (accepted).

[5] K. Takeda and H. Torikai, Experiments on a Hardware-Efficient Bio-Inspired Snake-like Robot, Prof. TJCAS, p. 72, 2017.